4.5 ADVANCED COMBUSTION ENGINE R&D

Advanced Combustion Engine R&D sub-program efforts are focused on removing critical technical barriers to commercialization of higher-efficiency, advanced ICEs in light-duty, medium-duty, and heavy-duty vehicles. This sub-program supports the mission of FCVT to develop more energy-efficient and environmentally friendly highway transportation technologies that enable the United States to use less petroleum. This sub-program is focused on improving engine efficiency while meeting future federal and state emissions regulations through a combination of (1) combustion technologies that minimize in-cylinder formation of emissions and (2) aftertreatment technologies that further reduce exhaust emissions. More-specific goals are to improve the peak brake thermal efficiency of ICEs for light-duty applications from 30 to 45% by 2012, and for heavy-duty applications from 40 to 55% by 2012 while meeting cost, durability, and emissions constraints. Work is done in collaboration with industry, national laboratories, and universities and in conjunction with the FreedomCAR and Fuel Partnership and the 21st CTP.

Advanced ICEs are a key element in the pathway to achieving the goals of the President's FreedomCAR and Hydrogen Fuel Initiative for transportation. Advanced engine technologies being researched and developed will allow the use of hydrogen as a fuel in ICEs, providing an energy-efficient interim hydrogen-based powertrain technology in the ultimate transition to hydrogen and/or fuel cell powered transportation vehicles. The FCVT Advanced Combustion Engine R&D sub-program is broken down into activities and outputs, along with collaborations, as shown in Figure 19.

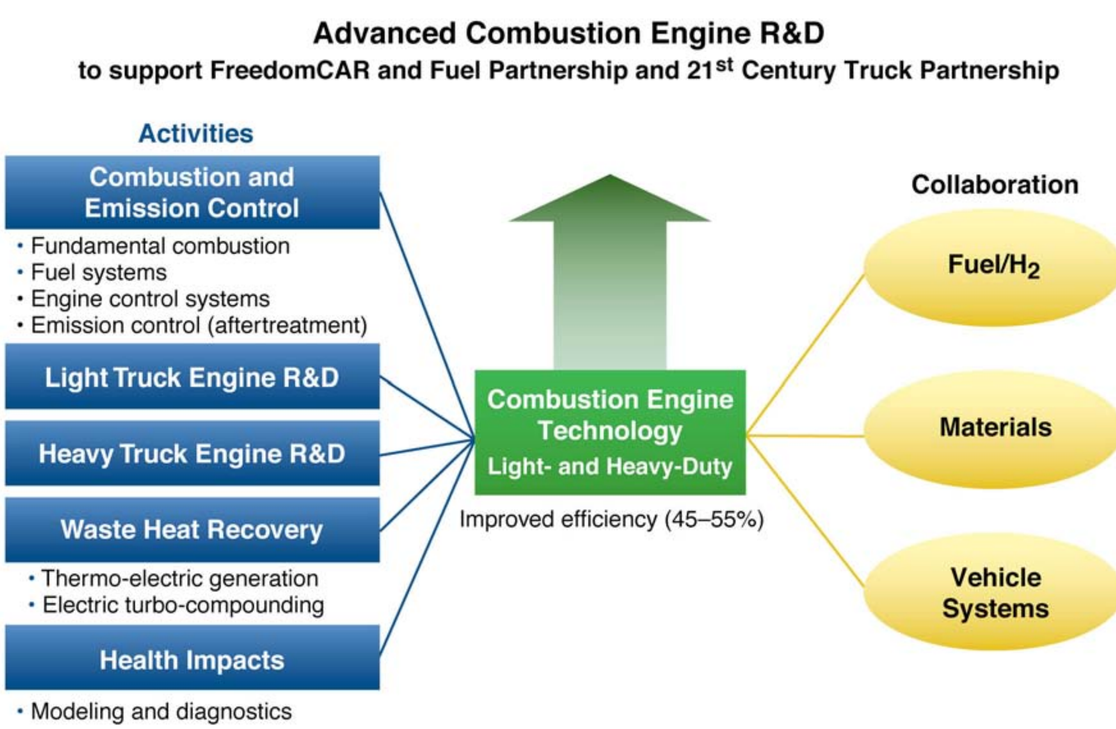


Figure 19. Advanced Combustion Engine R&D activities, outputs, and collaborations.

4.5.1 Combustion and Emission Control R&D

The Combustion and Emission Control R&D activity focuses on enabling technologies for energy-efficient, clean vehicles powered by advanced ICEs using clean hydrocarbon-based and non-petroleum-based fuels and hydrogen. R&D has been focused on developing technologies for light-, medium-, and heavy-duty compression ignition direct-injection (CIDI) engines and is being transitioned to developing technologies for advanced engines operating in combustion regimes that will further increase efficiency and reduce emissions to near-zero levels.

Goals

The FreedomCAR and Fuel Partnership goals for ICEs are as follows:

- By 2010, an ICE powertrain system costing $30/kW, having a peak brake engine efficiency of 45% and meeting emission standards.
- An ICE powertrain system operating on hydrogen with a cost target of $45/kW by 2010 and $30/kW in 2015, having a peak brake thermal efficiency of 45% and meeting emissions standards (this goal is shared with HFCIT).

The following goals are intended to enable FCVT to meet energy-efficiency improvement targets for advanced combustion engines suitable for passenger cars and light trucks, as well as to address technology barriers and R&D needs that are common between light- and heavy-duty vehicle applications of advanced combustion engines.

- By 2004, achieve CIDI engine efficiency of at least 38% and, combined with emission control devices, meet EPA Tier 2, Bin 5 full-useful-life emissions in a light-duty vehicle using diesel fuel (specified by the Fuels Technologies sub-program) with a fuel efficiency penalty of not more than 3%.
- By 2007, achieve CIDI engine efficiency of at least 41% and, combined with emission control devices, meet EPA Tier 2, Bin 5 in a light-duty vehicle using diesel fuel (specified by the Fuels Technology sub-program) with a fuel efficiency penalty of not more than 2%.
- By 2012, develop the understanding of novel low-temperature engine combustion regimes needed to simultaneously enable engine efficiency of 45% and a fuel efficiency penalty of less than 1%.

Programmatic Status

The CIDI engine, an advanced version of commonly known diesel engines, is the most promising technology for achieving dramatic energy-efficiency improvements in light-duty vehicle applications, where it is suited to both conventional and hybrid-electric powertrain configurations. The CIDI engine is also the primary engine for heavy-duty applications because of its high efficiency and durability. Moreover, the CIDI engine offers a propulsion platform with the potential for further significant efficiency improvements beyond its current capabilities. Although it is more efficient than conventional gasoline engines, if the CIDI engine is to become widely used in automotive applications and remain viable for heavy-duty applications, advancements will be required in the mid-term to further improve efficiency while meeting more stringent future emissions standards. Advancements will be required in clean combustion, emission control technology, and clean diesel fuels. Work on the CIDI engine for all applications, from light to heavy duty, supports the mid-term goals of the FreedomCAR and Fuel Partnership and 21st CTP, more specifically, the continued development of advanced technologies that will dramatically reduce the fuel consumption and emissions of all petroleum-fueled vehicles while meeting mandated emissions regulations.

The advanced combustion engine work being undertaken will be applicable to both passenger vehicles (cars and light trucks) and commercial vehicles (medium and heavy trucks and buses). Laser diagnostics are used for measuring fuel injection, fuel-air mixing, combustion, and emissions formation processes in-cylinder. The results provide the knowledge base needed to (1) design combustion systems that enable maximum engine efficiency and compliance with emissions standards and (2) develop the simulation tools for effectively optimizing engine designs. In the longer term, further improvement of the advanced engine designs to be considered (e.g., low-temperature combustion, increased expansion ratio, improved exhaust heat recovery, variable valve timing, reduced friction) and minimization of the emission reduction fuel economy penalty offer the potential for even further fuel efficiency gains for heavy- and light-duty vehicles.

Work is also undertaken in hydrogen-fueled ICE research that will provide an interim hydrogen-based powertrain technology that promotes the longer-range FreedomCAR and Fuel Partnership goal of transitioning to a hydrogen-fueled transportation system. This goal is shared by FCVT and HFCIT. Hydrogen engine technologies being worked on have the potential to provide CIDI-like engine efficiencies with near-zero emissions.

Advanced fuel formulations and fuel quality are also crucial to achieving higher energy efficiencies and meeting emissions targets. The EPA rule mandating that the sulfur content of highway diesel fuel be reduced to less than 15 ppm starting in 2006 will greatly benefit the effectiveness, durability, and life of emission control devices. Because of the importance of clean fuels in achieving low emissions, R&D tasks will be closely coordinated with the relevant tasks of the Fuels Technologies sub-program described in Sect. 4.7.

Targets

Presented in Table 22 are the technical targets for the Combustion and Emission Control activity. Shown also are the FreedomCAR and Fuel Partnership goals for both hydrocarbon- and hydrogen-fueled ICEs. These mostly apply to light-duty vehicles. The major technical targets in engines for light trucks and heavy trucks are discussed in Sections 4.5.2 and 4.5.3, respectively.

Barriers

The barriers to achieving the technical targets are as follows.

A. **Fundamental knowledge of engine combustion.** Engine efficiency improvement, engine-out emissions reduction, and minimization of engine technology development risk are inhibited by inadequate understanding of the fundamentals of fuel injection, fuel-air mixing, thermodynamic combustion losses, and in-cylinder combustion/emission formation processes over a range of

Table 22. Technical targets: Combustion and Emission Control activity					
Characteristics	Units	Fiscal Year			
		2004	2007	2010	2012
FreedomCAR and Fuel Partnership Goals					
ICE powertrain					
Peak brake thermal eff. (CIDI/H_2–ICE) (H_2–ICE)	%			45/45 45 (2015)	
Cost (CIDI/H_2–ICE)	$/kW			30/45	
(H_2–ICE)				30 (2015)	
FCVT Combustion and Emission Control Goals					
Reference peak brake thermal efficiency[a]	%	30	32	34	35
Target peak brake thermal efficiency/part-load brake thermal efficiency (2 bar BMEP[b] @1500 rpm)	%	38/25	41/27	43/29	45/31
Powertrain cost[c,d]	$/kW	30	30	30	30
Emissions[e]	(g/mile)	Tier 2, Bin 5	Tier 2, Bin 5	Tier 2, Bin 5	Tier 2, Bin 5
Durability[e]	Hrs.	5000	5000	5000	5000
Fuel efficiency penalty due to emission control devices[f]	(%)	<3	<2	<1	<1

[a] Current production, EPA-compliant engine.

[b] Brake mean effective pressure.

[c] High-volume production: 500,000 units per year.

[d] Constant out-year cost targets reflect the objective of maintaining powertrain (engine, transmission, and emission control system) system cost while increasing complexity.

[e] Projected full-useful-life emissions for a passenger car/light truck using advanced petroleum-based fuels as measured over the Federal Test Procedure as used for certification in those years.

[f] Energy used in the form of reductants derived from the fuel, electricity for heating and operation of the devices, and other factors such as increased exhaust back-pressure, reduce engine efficiency. A cycle average thermal efficiency loss of 1 to 2% is equivalent to a 3 to 5% fuel economy loss over the combined Federal Test Procedure drive cycle.

combustion temperature regimes of interest, as well as by an inadequate capability to accurately simulate these processes. The lack of knowledge base will inhibit the development of combustion systems using advanced, low-temperature combustion (LTC) or mixed-mode combustion systems that operate effectively over the full load range of an engine. These advanced combustion systems offer significant potential for providing engines that operate with CIDI-like engine efficiencies over the full load range while meeting EPA Tier 2 emissions standards with greatly reduced aftertreatment system requirements.

B. **Emission control.** Meeting EPA oxides of nitrogen (NO_x) and particulate matter (PM) emissions standards with little or no fuel economy penalty will be one of the keys for market entry of CIDI and advanced combustion engines. NO_x adsorbers appear to be the most viable NO_x reduction devices for light-duty vehicles, but they are very sulfur-sensitive, resulting in an increased energy penalty over time to compensate for loss of activity. Others under consideration have their own technical barriers as well. Particulate trap technology is costly, and some regeneration technologies are energy-intensive. The most effective particulate trap technologies cause reductions in engine efficiency through increases in backpressure. While there is more experience with PM emission control devices than with NO_x control devices, PM control technology will likely be pushed to its limits in favor of controlling NO_x emissions, which currently is the more intractable of the two problems.

C. **Engine controls.** Effective sensing and control of various parameters will be required to optimize operation of engines in advanced LTC regimes over a full load-speed map similar to that of the CIDI engine. These include control of (1) ignition timing across the load-speed map, (2) the rate of heat release, and (3) transients and cold starts.

D. **Cost.** The emission control devices required by engines to meet emission targets add costs to the system. Better use of advanced LTC modes to reduce the formation of emissions in-cylinder will reduce aftertreatment system requirements and associated costs. In addition, CIDI engines and some of the engines envisioned that use LTC are more expensive than conventional, port fuel-injected, spark-ignited engines because the engine structures must be stronger to accommodate the inherently higher combustion pressures, and the high-pressure fuel injection systems must be correspondingly more robust.

Approach

The Combustion and Emission Control activity will simultaneously address in-cylinder combustion and emission control, exhaust aftertreatment technologies, and fuel formulation strategies for the most cost-effective approach to optimizing advanced combustion engine efficiency and performance while reducing emissions to meet future EPA standards. Experimental data and validated computer simulation models will be developed to provide a more definitive understanding of the in-cylinder fuel injection, combustion, and emissions formation processes and the evolution of emissions in the aftertreatment systems. The models that will be developed will enable rapid and effective optimization of the fuel injection and combustion systems and the aftertreatment devices for maximum overall system efficiency, compliance with emissions standards, and cost-effectiveness. The experimental research and modeling tasks will allow a more effective evaluation of potential technologies and validation of technology selection. Working at the forefront of these new technologies will enhance the knowledge base that can be used by industry partners and suppliers (e.g., original equipment manufacturers, engine manufacturers, emission control device manufacturers, catalyst suppliers) to develop energy-efficient, cost-effective advanced engine/emission control systems.

Fundamental combustion R&D will focus on developing greater understanding of the combustion and emissions processes and their dependence on fuel spray characteristics, in-cylinder air motion, and fuel selection so that pathways to higher engine efficiencies and lower NO_x and PM from the engine can be identified. R&D tasks will include the identification of advanced combustion system concepts that enable high efficiencies and fuel injection strategies for implementing the advanced combustion systems, research on combustion systems for advanced fuels, investigation of mechanisms and strategies to reduce thermodynamic combustion losses, investigation of NO_x and PM formation mechanisms in the engine, and identification of potential fuel-derived reductants. Numerical and chemical kinetics models will be developed to guide the experimental combustion research.

Advanced combustion engine technologies that will be pursued operate in LTC regimes that can provide high, diesel-like efficiencies and have ultra-low engine-out

NO_x and particulate levels. The engines that will be investigated include engines operating purely on LTC modes, such as the homogeneous charge compression-ignition engine (HCCI); and engines that use conventional CIDI or spark-ignited (SI) combustion modes for starting and at higher loads, and use LTC modes at moderate to light loads, referred to as mixed-mode operation. In the case of mixed-mode operation with CIDI at high loads, the high-efficiency, high-load capabilities of CIDI are coupled with the high-efficiency, low-emission capabilities of the LTC modes, overcoming the deficiencies in CIDI aftertreatment systems at light loads and the limited high-load capabilities of LTC modes. In the case of mixed-mode operation with SI at high loads, CIDI-like engine efficiencies can be achieved by using LTC at moderate to light loads to eliminate part-load throttling losses and to control emissions, while maintaining the high-load capabilities of conventional port-fuel-injected engines.

Research will also be undertaken to develop a fundamental knowledge base on very lean, low-temperature hydrogen combustion under high-pressure in-cylinder conditions. This will support the development of both advanced hydrogen-fueled engines and the simulation tools used to aid the development of the knowledge base and the optimization of engines. This will require improved understanding of hydrogen injection and fuel-air mixing processes; combustion stability, combustion duration and pre-ignition phenomena; emissions formation; and the effects of engine speed and load, combustion chamber geometry, and in-cylinder air motion (e.g., swirl) on hydrogen combustion and emissions processes.

Fuel systems R&D focuses on injector controls and fuel spray development. The fuel injection system pressure and fuel spray development influence the spray penetration and fuel-air mixing processes and thus combustion and emissions formation within the combustion chamber. These phenomena are being researched using X-ray and optical diagnostics. In-cylinder emissions reduction can also be achieved with very careful control of injection timing, duration, and rate shape. Recent developments have shown that the application of multiple injections in a cycle can result in much lower engine-out emissions.

Engine control systems R&D will focus on developing precise engine control and flexibility in engine controls that are enabling technologies for improved efficiency and emission reduction in advanced combustion engines. These control system technologies will facilitate adjustments to parameters such as intake air temperature, fuel injection timing, injection rate, variable valve timing, and EGR to allow advanced combustion engines to operate over a wider range of engine speed/load conditions. In addition, control strategies will be developed to enable the effective transition from low-temperature, low-emission modes of combustion used at lighter loads to conventional CIDI or SI combustion at higher loads (i.e., control strategies for mixed-mode operation).

Complex, precise engine and emission controls will require sophisticated feedback systems employing new types of sensors. NO_x and PM sensors are in the early stages of development and require additional advances to be cost-effective and reliable, but they are essential to control systems for these advanced engine/aftertreatment systems.

Development of technologies enabling LTC will be undertaken to achieve the best combination that enables meeting maximum fuel economy and performance requirements. These include variable compression ratio (VCR), variable valve timing, variable boost, advanced sensors, and exhaust emission control devices (to control hydrocarbon emissions at idle-type conditions) in an integrated system. Variable valve control, independent valve control, and VCR offer the potential for operating with the highest efficiency and providing control of ignition timing through control of in-cylinder temperature or internal EGR. These technologies can reduce engine-out NO_x emissions and thus reduce the need for ancillary systems such as external EGR.

Emission control system R&D tasks will focus on reducing the energy-efficiency penalty of emission control systems through development of more-effective emission control devices for reducing NO_x and PM in exhaust systems.

Research on improving the effectiveness of NO_x adsorbers for diesel engine exhaust aftertreatment will focus on (1) defining the optimum regeneration schedule with a lean-burn engine, (2) improving NO_x reduction at the lower exhaust temperatures of the duty cycle for light vehicles, and (3) determining long-term degradation mechanisms and susceptibility to sulfur poisoning. Work will continue on selective catalytic reduction (SCR) of NO_x using urea (ammonia) as a reductant. Several challenges will be addressed, such as issues of ammonia slip and other unregulated emissions, the complexity of the urea injection and control system for transient engine operation, and exploration of alternatives to urea. As lower engine-out emissions are achieved, continuous lean-NO_x catalysis again becomes a viable alternative. High-throughput combinatorial chemistry will be employed to develop lean-NO_x catalyst materials with higher conversion rates and greater durability. Several common issues—such as sulfur tolerance, reductant optimization, and long-term degradation mechanisms—crosscut among all the NO_x-reducing technologies and will be investigated.

PM-reduction devices face challenges in the areas of long-term degradation and the ability to regenerate effectively despite the relatively cool exhaust temperatures typical of light-duty CIDI-engines. The focus will be on the refinement of existing technologies and development of novel and innovative PM control technologies. Three different PM-reducing technologies—the catalyzed diesel particulate filter, the continuously regenerating diesel particulate filter, and the microwave-regenerable filter—will continue to be pursued. Research will focus on evaluations of their potential to meet the PM emissions targets, especially in conjunction with NO_x-reducing technologies. To help improve the understanding of PM formation and in-cylinder control, especially during engine transients, new high-energy, laser-based diagnostics with real-time capabilities for measuring and characterizing PM emissions at low concentrations will be used. Other PM enabling technologies that will be investigated include sulfur traps, sulfur-tolerant catalysts, and oxidizing catalysts used in conjunction with PM-reducing devices.

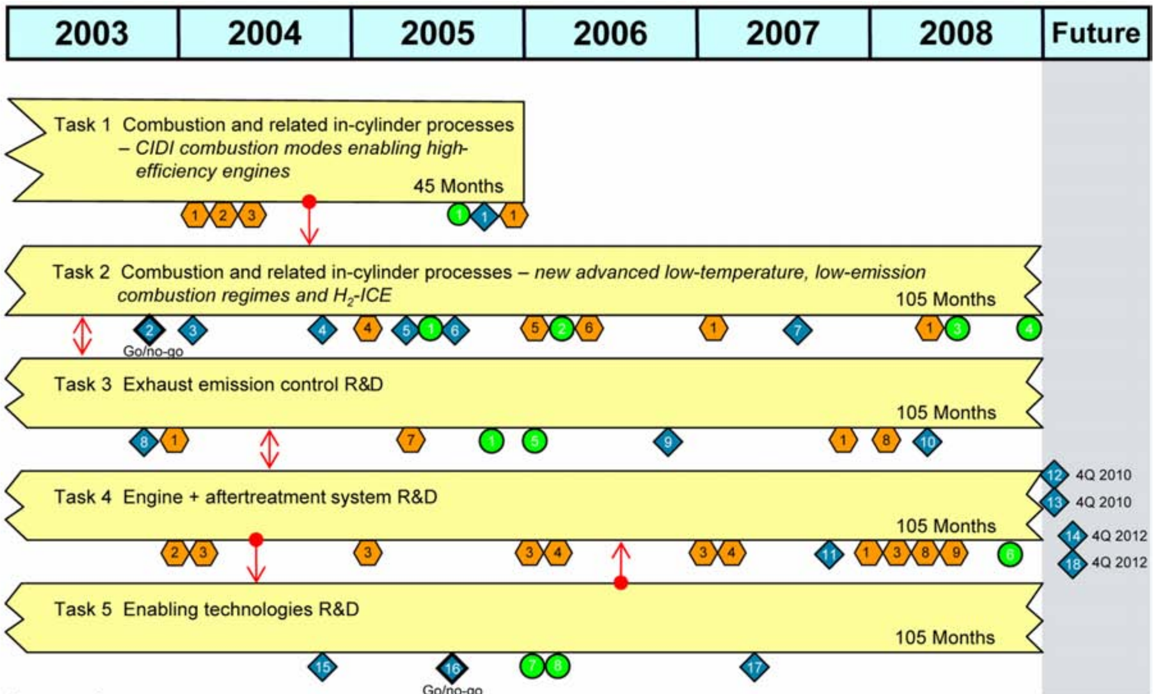
Task Descriptions

A description of each task, along with the estimated duration and the barriers associated with the task, is provided in Table 23. These tasks support the FreedomCAR and Fuel Partnership short- and mid-term goals. They were initiated in January 2002 together with the inception of the FreedomCAR Partnership and, with the exception of Task 1, which ends in 2005, will continue through 2012.

Table 23. Tasks for Combustion and Emission Control R&D		
Task	**Title**	**Duration/ barriers**
1	Combustion and related in-cylinder processes—CIDI combustion modes enabling high-efficiency engines • Improve fundamental understanding of combustion and in-cylinder emissions formation processes and their dependence on fuel injection, combustion chamber, in-cylinder air motion, and chemical kinetic processes through experimental and modeling/simulation approaches	45 months Barriers A,B
2	Combustion and related in-cylinder processes—new advanced low-temperature, low emission combustion regimes and H_2-ICE • Develop fundamental understanding of low-temperature combustion regimes and their control over a range of engine loads and speeds through experimental and modeling/simulation approaches • Exploit emissions characteristics of LTC regimes and methods of coupling to aftertreatment systems to achieve maximum efficiency • Establish relationships between new combustion regimes and potential efficiency gains and develop paths to efficiency targets • Develop understanding and methods for mixed-mode approaches that must alternate between conventional and new combustion regimes • Fundamental combustion and modeling of H_2-ICE	129 months Barriers A, B, D
3	Exhaust Emission Control R&D • Improve the scientific foundation of NO_X adsorber–catalyst performance and degradation mechanisms to mitigate the trend of greater efficiency loss as catalyst ages • Develop strategies for mitigating sulfur effects on aftertreatment, including catalyst tolerance, regeneration methods, and further reduction of sulfur sources (lubricants) • Improve the catalyst materials and systems for lean NO_X catalysis with urea and alternative reductants for performance over wider temperature range • Improve the simulation capability for exhaust aftertreatment devices to accelerate the design of the most efficient and effective emission control systems • Improve the technologies and strategies for PM filters to achieve reliable regeneration at low exhaust temperatures	129 months Barrier B, D
4	Engine + Aftertreatment System R&D • Develop and demonstrate integrated controls and strategies for engine and aftertreatment systems with maximum fuel economy at the necessary emissions levels	129 months Barriers A, B, C
5	Enabling Technologies R&D • Develop and validate NO_X and PM sensors for engine and aftertreatment control and diagnostics • Develop advanced engine control methods and strategies for operation over a range of loads and speeds • Research, develop, and evaluate sulfur trap technologies for both on-board fuel lines and SO_2 in exhaust	129 months Barriers B, C

Milestones

Combustion and Emission Control R&D activity milestones are provided in the following network chart.



Legend

Milestone

1. Complete essential experiments and models of "conventional" diesel combustion
2. Confirm simultaneous NO_x and PM reductions feasibility on the order of >80% at up to 40% load using LTC modes. **Go/no-go** on LTC path
3. Complete upgrades of experimental labs for study of LTC regimes
4. Complete H_2-ICE laboratory
5. Improve KIVA-3V simulation of new combustion modes.
6. Determine the mixing characteristics of H_2 under direct-injection conditions
7. Expand operating range of HCCI combustion
8. Validate new simulations for aftertreatment devices and transfer to industry
9. Validate NO_x and PM control device efficiencies (sufficient to limit NO_x to 0.07 g/mile and PM to 0.01 g/mile, respectively) using 15-ppm sulfur-content fuel with durability to projected full-useful-life requirements
10. Complete evaluation of catalyst materials using combinatorial chemistry
11. Validate 45% thermal efficiency with <3% fuel efficiency penalty for meeting standards with emission control devices using a fuel formulation recommended by the Advanced Petroleum-Based Fuels (APBF) sub-activity
12. Validate 43% peak thermal efficiency H_2 ICE
13. Validate 46% thermal efficiency with <2% fuel economy penalty for meeting standards with emission control devices using a fuel formulation recommended by the APBF sub-activity
14. Validate 45% thermal efficiency with <1% fuel economy penalty for meeting standards with emission control devices using a fuel formulation recommended by the APBF sub-activity
15. Test and validate the operation of prototype NO_x/PM sensors as part of an engine system
16. Determine the feasibility of exhaust sulfur trapping, including durability, regeneration, and efficiency. **Go/no-go** on using sulfur traps
17. Evaluate sensors to control HCCI combustion
18. Validate 45% peak thermal efficiency of H_2 ICE

Technology Program Output

1. Transfer of technical data/information to industry
2. Technical results to Light Truck Engine R&D
3. Technical results to Heavy Truck Engine R&D
4. Engine/emission control system model that predicts fuel effects on the system, to Fuels Technologies R&D
5. Fuel Property requirements for HCCI, to Fuels Technologies R&D
6. Technical results on H_2-ICE to Hydrogen, Fuel Cells, and Infrastructure Technologies Program
7. Rapid aging protocol for NO_x adsorber system, to Fuels Technologies R&D
8. Technical results and feedback to Fuels Technologies
9. Technical results to Vehicle Systems R&D

Supporting Input

1. Fuel formulation that enables emission control system to meet useful life requirements, from Fuels Technologies R&D
2. Input from Hydrogen, Fuel Cells, and Infrastructure Technologies Program
3. Fuel-derived reductant for emission control use, from Fuels Technologies R&D
4. Fuels composition that meets requirements of HCCI, from Fuels Technologies R&D
5. Technical data on fuel sulfur trap, from Fuels Technologies R&D
6. Validated catalyst and PM filter materials to enable fuel efficiency and meet 2007 – beyond emissions goals, from Heavy Vehicle Propulsion Materials
7. Validated emission control devices (sensors, PM filter), from Automotive Propulsion Materials
8. New, high performance material for heavy vehicle fuel systems to meet fuel efficiency and 2007 and beyond, from Heavy Vehicle Propulsion Materials

4.5.2 Light Truck Engine R&D

The Light Truck Engine R&D activity uses the expertise of U.S. heavy-duty diesel engine manufacturers in developing high-efficiency, low-emission diesel engines for light trucks [pickup trucks, vans, and sport-utility vehicles (SUVs)] that can achieve at least a 50% improvement in on-road fuel economy over gasoline-fueled vehicles and provide the power needed for four-wheel drive, hauling, and towing (popular features of pickups and SUVs).

Goals

The specific goal of this activity is

> By 2004, in collaboration with industry partners, complete development of advanced clean diesel engine technologies that enable commercial production of pickup trucks, vans, and SUVs that achieve at least a 50% fuel economy improvement relative to current gasoline-fueled trucks while demonstrating Tier 2 emission standards.

Programmatic Status

The Light Truck Engine R&D activity was initiated in 1997 as a means of impacting the fuel consumption of the rapidly growing U.S. light truck market, which is dominated by inherently low-fuel-economy (miles-per-gallon) gasoline-fueled vehicles. Diesel engines are offered in the heavier light trucks (over 8500 lb gross vehicle weight), which have maintained solid sales (approximately 300,000 units per year) for the last 5 to 8 years. Additional sales are limited by engine supply and lack of availability of a nominal 200–250 hp diesel engine capable of meeting the more stringent vehicle emissions standards applicable to light trucks of less than 8500 lb gross vehicle weight, which represent a majority of light trucks. Penetration of high-efficiency diesel engines in this light truck market segment will require a very different engine design—one that meets EPA Tier 2 vehicle emissions standards and is competitive with the gasoline engine in performance and noise, vibration, and harshness (NVH), with greater engine service life and consumer-desired attributes, including cost. Accordingly, the Light Truck Engine R&D activity focuses on the development of clean diesel engines for the light truck market.

This activity has completed dynamometer tests of light trucks with prototype diesel engines installed to replace production gasoline engines and has validated the achievement of at least a 50% improvement in fuel economy (miles per gallon) and EPA Tier 2 emissions. This activity is due to be completed in 2004 with achievement of the technical targets.

Targets

The targets for Light Tuck Engine R&D are shown in Table 24.

Table 24. Technical targets for Light Truck Diesel Engine R&D

Characteristics	Units	Fiscal year	
		2002 Status	2004
Engine power	hp	225–300	225–325
Fuel economy increase over equivalent gasoline vehicles	%	>50	>50
Engine cost (compared with equivalent gasoline engine)	%	<120	<120
Engine weight (compared with equivalent gasoline engine)	%	<110	<110
NVH (compared with equivalent gasoline engine)	db difference	<3	<1
NO_X emissions[a]	g/mile	<0.30	<0.07
PM emissions[a]	g/mile	<0.01 for 20 h in test cell	0.01
Durability[b] (on lab dynamometer, computer-simulated vehicle miles)	Miles (equivalent)	>20,000	>100,000

[a] Projected full-useful-life emissions for an SUV (using advanced petroleum-based fuels with 15 ppm sulfur) as measured over the Federal Test Procedure as used for certification in those years.

[b] Projected full-useful-life durability, as measured over the Federal Test Procedure as used for certification.

Barriers

A. **Cost.** Although pricing practice does not always reflect cost, the diesel option, for the few vehicles where it is available, costs at least $1000 more (in some cases, much more) than the base gasoline engine. The fuel injection system for diesels, necessarily complex to achieve fine control of injection spray at high pressure, is one of the key cost drivers. The fuel injection system is critical to engine performance, efficiency, and emissions. Further adding to the cost is the air-handling system, including the turbocharger, after-cooler, and related hardware that diesels need in order to have competitive power density and responsiveness.

B. **Emissions.** Meeting NO_x and particulate emission regulations with engines of high efficiency and low cost is a significant barrier, particularly in the higher power range necessary for light trucks. For in-cylinder controls, further development of EGR is necessary for heavy-duty diesels if they are to be scaled down for pickups. Cooled EGR has not been adequately developed for full commercialization. Fuel injection systems have achieved recent advancements, but additional control of injection rate is thought to be needed. Aspects of the fuel/air mixing process are still insufficiently understood and modeled to optimize engine design. Additionally, lean-burn NO_x aftertreatment systems are not sufficiently developed for commercial application. Current oxidation catalysts eliminate only 30–40% of PM, which may be inadequate for future emission goals.

C. **Noise, vibration, and harshness.** While the diesel has a recognized advantage over the gasoline engine in fuel efficiency, it is also perceived to have significant relative shortcomings in the areas of NVH. These shortcomings are being ameliorated through improved design and component development.

Approach

Under cooperative agreements (with 50% cost share), three teams (led by heavy-duty diesel engine manufacturers and in partnership with U.S. automakers) will continue R&D of clean diesel engines of the power rating and duty cycle appropriate for light trucks under 8500 lb gross vehicle weight rating. A second-generation pre-production prototype clean diesel engine (200 to 250 hp) will be optimized for emissions, performance, cost, and noise. The engine cost and weight are expected to be about 20% higher than for production gasoline engines. NVH levels are expected to be similar to those of the gasoline engine. The optimized engine will be installed in a light truck (SUV or pickup truck) to be tested in real-world driving conditions. The clean diesel engine–powered light truck should show a fuel economy improvement of 50% over comparable gasoline engine–powered vehicles. Two of the teams are focused on successfully meeting the fuel economy goals, which will be followed by achieving low emission requirements while maintaining high fuel economy. Vehicle emission levels will not exceed EPA Tier 2 emissions at this stage. The third team will continue to focus on the development of advanced combustion technologies and emission controls that will set new low levels for engine-out NO_x and particulates.

Task Descriptions

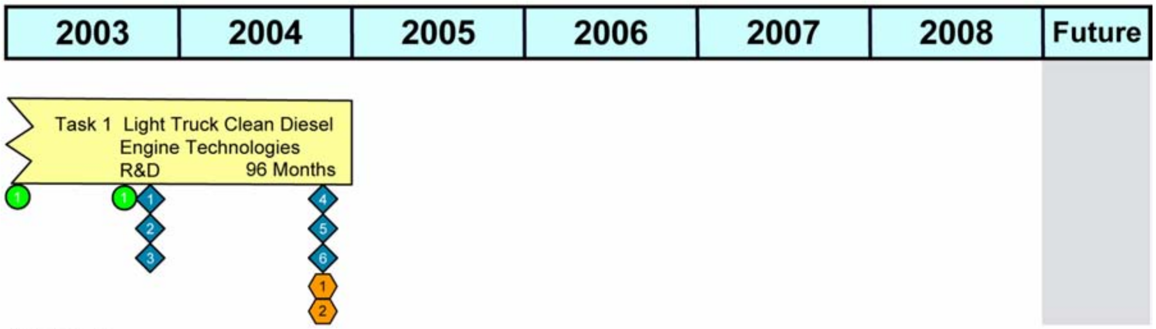
A description of each technical task, along with the estimated duration and technical barriers associated with the task, is provided in Table 25.

Table 25. Task for Light Truck Engine R&D

Task	Title	Duration/ barriers
1	Light Truck Clean Diesel Engine Technologies R&D • Develop pre-production prototype clean diesel engine (200 to 250 hp) that is optimized for efficiency, performance, emissions, cost, and noise • Install advanced clean diesel engine in a representative light truck and conduct in-vehicle testing under real-world driving conditions • Develop advanced combustion technologies and emission controls for advanced clean diesel engine	90 months Barriers A, B, C

Milestones

Light Truck Engine R&D activity milestones are provided in the following network chart.



Legend

Milestone	Technology Program Output	Supporting Input
1. Reduce light truck diesel engine weight to not greater than 1.1 times that of an equivalent gasoline engine 2. Increase diesel engine power output to between 225 and 325 hp 3. Increase fuel economy of diesel-powered light truck to at least 1.5 times that of comparable gasoline vehicle with Tier 2 emission compliance in a laboratory 4. Validate NVH levels in production prototype engine to within 1 db of comparable gasoline engine 5. Validate on-road vehicle fuel economy of diesel-powered light truck of at least 1.5 times that of a comparable gasoline vehicle, with EPA Tier 2 emissions 6. Validate compliance with EPA Tier 2 Bin 5 for 120,000 miles equivalent	1. Technical data to industry 2. Technical data to Vehicle Systems R&D	1. Input from Combustion and Emission Control R&D

4.5.3 Heavy Truck Engine R&D

Heavy Truck Engine R&D is focused on increasing heavy-duty diesel engine efficiency significantly above current levels, as well as addressing efficiency penalties resulting from technologies required to meet increasingly stringent emissions standards. The engine efficiency losses would result in higher operating costs to truck owners and operators and, ultimately, higher costs to consumers. On a national scale, increased heavy truck fuel efficiency will result in reduced petroleum demand.

Goals

The long-term (2012) goal of this activity is to develop the technologies that will increase the thermal efficiency of heavy-duty diesel engines to at least 55% while reducing emissions to near-zero levels. More specifically,

- By 2005, increase the efficiency of heavy-duty diesel engines from 40 to 45% while meeting EPA 2007 emission standards.
- By 2007, increase the thermal efficiency of heavy-duty engines to 50% while meeting EPA 2010 emission standards.
- By 2012, increase the thermal efficiency of heavy truck engines to 55% while meeting prevailing EPA emissions standards.

This activity also supports the goal of 21st CTP to develop and validate a commercially viable, 50% efficient, emissions-compliant engine system for Class 7 and 8 highway trucks by 2010.

Programmatic Status

With the acceleration to October 2002 of the enactment of the 2004 EPA heavy-duty engine statement-of-principles emissions standards, the Heavy Truck Engine R&D activity was initiated in FY 1999 to address the anticipated heavy-duty diesel engine efficiency penalty that would occur. Having to meet the standards sooner using only currently available emissions control technologies was expected to result in an efficiency penalty of as much as 10% in heavy-duty diesel engines. In addition, the sulfur content of available diesel fuel has deleterious effects on the performance of emission control devices. The primary objective of this research is to increase the engine thermal efficiency and develop emission control technologies that would have minimal impact on engine efficiency.

In December 2000, EPA enacted the 2007 Heavy-Duty Diesel Engine Emissions Standards. EPA also issued a rule in January 2001 requiring that 80% of all on-road diesel fuel have less than 15 ppm sulfur, starting in 2006. This rule is in conjunction with the phase-in of standards in the 2007–2010 timeframe. The rule on sulfur content of diesel fuel is expected to greatly benefit the performance and durability of emissions control technologies under development. The Heavy Truck Engine activity supports the development of technologies needed to significantly improve the efficiency of heavy-duty diesel engines beyond present levels while meeting the 2007 heavy-duty engine emissions standards, as well as anticipated future standards.

Targets

The technical targets for Heavy Truck Engine R&D are shown in Table 26.

Table 26. Technical targets: Heavy Truck Diesel Engine R&D

Characteristics	Year			
	2002 status	2005	2007	2012
Engine thermal efficiency, %	>40	>45	>50	>55
NO_X emissions,[a] g/bhp-h	<2.0	<1.2	<0.20	<0.20
PM emissions,[a] g/bhp-h	<0.1	<0.01	<0.01	<0.01
Stage of development	Commercial	Prototype	Prototype	Prototype
Durability, miles (equivalent)	>100,000	>200,000	>400,000	

[a] Using 15-ppm sulfur diesel fuel

Barriers

The technical barriers to achieving dramatically improved efficiency and near-zero emissions in heavy truck engines are as follows:

A. **Efficiency.** There are several barriers to improving engine efficiency. In-cylinder NO_x reduction methods in conventional diesels, using traditional combustion modes, limit efficiency by limiting peak in-cylinder temperatures and the time spent at peak temperatures. Aftertreatment systems have energy penalties that reduce the overall engine/aftertreatment system energy efficiency. Current commercially viable materials and lubricants limit engine efficiency by limiting peak temperatures and pressures at which critical engine components can operate.

B. **Emissions.** The key barriers to achieving the emissions reduction targets for heavy truck diesel engines include (1) maintaining efficiency and low NO_X while keeping PM down; (2) incomplete development of aftertreatment technology, especially for NO_X; and (3) immature simulation and control systems integration, as well as static and dynamic optimization of multiple emission reduction systems. Common to each barrier is a lack of adequate simulation capabilities and readily implemented sensing and process control systems. Improved simulation capabilities are needed to optimize both the combustion and aftertreatment systems so as to transform a "statically" integrated system into an optimized overall engine/aftertreatment package that results in maximum efficiency and performance and minimum emissions. In turn, a mature and robust sensing and control system will monitor and navigate these multiple systems over the complex "dynamics" of normal over-the-road vehicle operation, while yielding the best vehicle fuel economy, performance, and emissions.

C. **Durability.** The barrier to achieving 435,000-mile durability for heavy-duty engines and their emission control systems is the premature degradation of the emission control devices due to operation under high-temperature and high-flow-rate conditions.

Approach

An integrated systems approach involving engine design, fuels, and aftertreatment technologies is required to simultaneously address fuel efficiency and emissions. R&D in combustion, materials, fuels, and aftertreatment devices provides the foundation for technology advancement, including simulations (virtual labs) in concert with controls development and experimentation.

Approaches to improving engine efficiency are effectively built upon understanding the energy losses. The combustion process, mechanical friction, heat transfer, air handling, and exhaust losses all are important in improving engine efficiency. Major elements of the technical approach include the following:

- Define baseline engine designs in sufficient detail to delineate the areas of required technology advancement. This would be a guide for enabling technology tasks. Conduct, on a continuing basis, analysis and supporting validation tests to assess progress toward goals.
- Optimize the mechanical design and combustion system for increased expansion ratio and thermodynamic efficiency.
- Develop and integrate cost-effective exhaust-heat-recovery technologies into the engine system.
- Improve the fundamental understanding of diesel combustion/emissions formation processes and exhaust aftertreatment systems, and the predictive simulation capabilities for these processes and systems needed to more effectively optimize performance.
- Develop and exploit advanced fuel injection and engine control strategies and new LTC regimes for their potential efficiency gains, with modeling and simulation as an integral component of the system design strategy.

- Improve turbocharger and/or air handling systems and controls, and trade-offs between efficiency and transient response. Develop new low-inertia materials and response-enhancing technologies.
- Continue the refinement of piston/cylinder designs, valve trains, and other mechanical components for reduced friction losses.
- Develop accurate, robust sensors for control systems.
- Conduct materials R&D in support of engine efficiency (this area is covered in the Materials Technology Section).

Simultaneous attainment of thermal efficiency targets and future required emissions reductions requires unprecedented attention to the effective integration of multiple, new system technologies. At the historical and most fundamental level, systems optimization and component performance was/is accelerated through the application of computer simulations. High-order “off-line” calculations are emphasized and crucial to understanding and defining the basic engine configuration and its performance and emission signature. However, given the number of prerequisite systems and many additional orders of complexity relative to the historical engine, new techniques are required to enable implementation of a coherent multi-system integration. Simulation and control techniques are active companions in the diesel engine development and operational process. A high-priority need is the advancement of computational simulation capabilities for all systems, especially for aftertreatment systems, which are currently in an immature state of development. Major elements of the technical approach to meet emissions targets also include these:

- Further develop flexible fuel-injection systems and engine control strategies and new combustion regimes for their emissions reduction potential, integrating modeling and simulation with engine controls development.
- Optimize cooled EGR for maximum NO_x reduction and minimum PM emission, mitigating durability concerns with EGR through materials engineering and operational controls.
- Improve the fundamental understanding of diesel combustion/emissions formation processes and exhaust aftertreatment systems, and the predictive simulation capabilities for these processes and systems needed to minimize emissions.
- Develop strategies for mitigating the effects of sulfur on aftertreatment, including catalyst tolerance, regeneration, and further reduction of sulfur sources (lubricants).
- Improve the scientific foundation of NO_x adsorber-catalyst performance and degradation mechanisms. Improve the catalyst materials and systems for lean NO_x catalysis with urea and alternative reductants for performance over a wider temperature range. Determine plasma benefits.
- Improve methods for generating and introducing NO_x reductants to catalysts.
- Develop suitable technologies and procedures for urea supply for selective catalytic reduction systems.
- Develop and apply sensors in controls and diagnostics of engine and emission control processes.
- In the development of emissions control devices, include features necessary to make the devices suitable for retrofit on existing trucks.

- Conduct materials R&D in support of emission reduction (addressed in Materials Technology, Section 4.6.)

Fuel properties, in particular sulfur content, are pivotal in whether NO_x adsorber catalysts will be successful. Work in fuels is coordinated with the Fuels Technology Team and is discussed in Fuels Technology, Section 4.7.

Task Descriptions

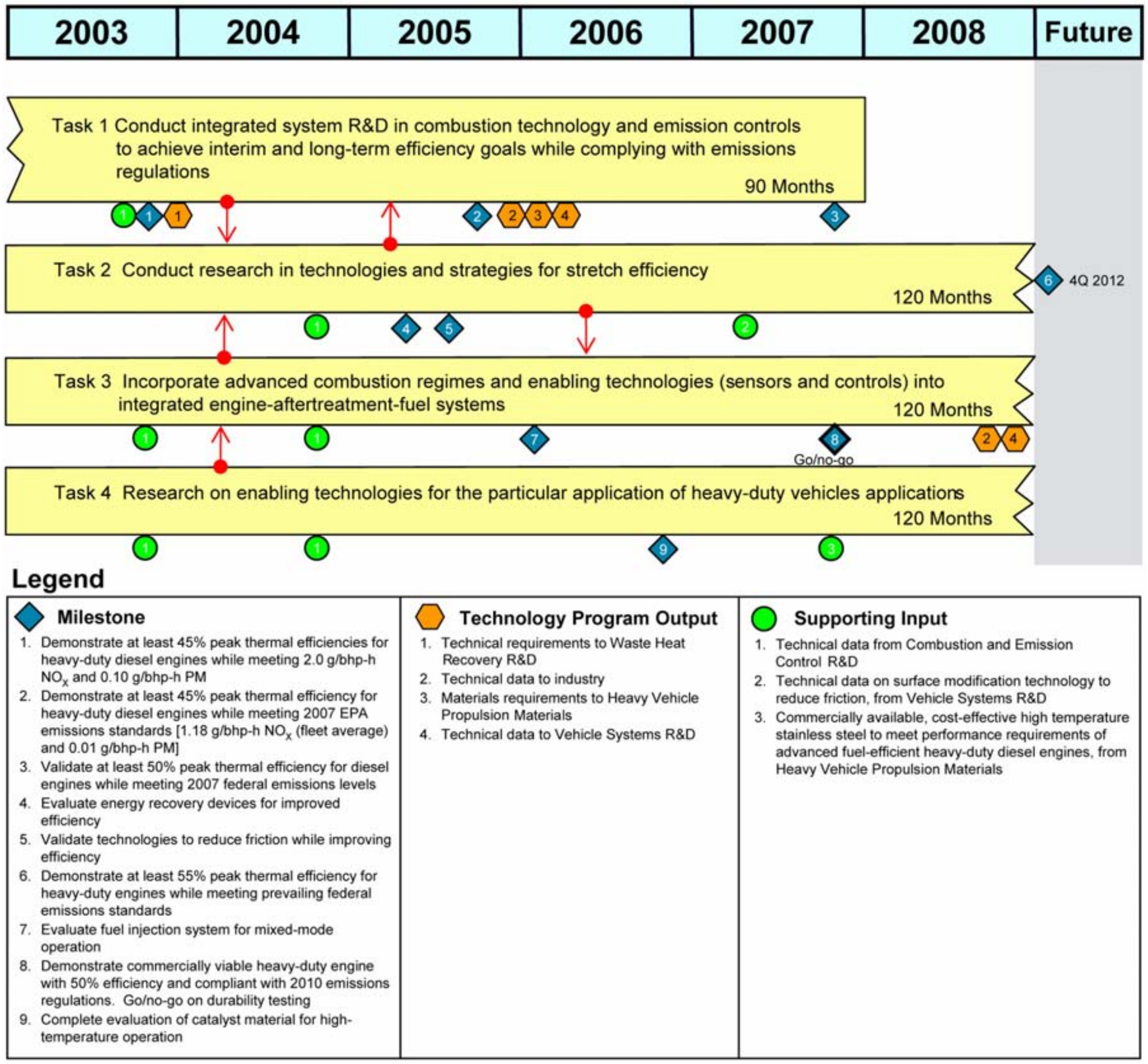
A description of each technical task, along with the estimated duration and technical barriers associated with the task, is provided in Table 27. Tasks 2, 3, and 4 commenced with the rejuvenation of 21st CTP in November 2002 and will continue through 2012.

Table 27. Tasks for Heavy Truck Engine R&D

Task	Title	Duration/ barriers
1	Conduct integrated system R&D in combustion technology and emission controls to achieve interim and long-term efficiency goals while complying with emissions regulations	90 months Barriers A,B, C
2	Conduct research in technologies and strategies for stretch efficiency • exhaust heat utilization • mitigating thermodynamic combustion losses • reduced parasitic losses • reduced air handling losses • improved thermal management	120 months Barrier A
3	Incorporate advanced combustion regimes and enabling technologies (sensors and controls) into integrated engine–aftertreatment–fuel systems	120 months Barriers A,B, C
4	Conduct research in enabling technologies for the particular application of heavy-duty vehicles, for example • sensors • sulfur traps • catalyst and filter fundamentals	120 months Barrier B

Milestones

The Heavy Truck Engine R&D activity milestones are provided in the following network chart.



4.5.4 Waste Heat Recovery

The Waste Heat Recovery activity develops technologies to convert waste heat from engines to useful energy (e.g., electrical energy) to improve overall thermal efficiency and reduce emissions.

Goals

The longer-term goal of this activity is to develop the technologies for recovering engine waste heat and converting it to useful energy that will improve overall diesel engine thermal efficiency to 55% while reducing emissions to near-zero levels. More specifically,

- By 2010, enable commercially viable turbocompound units that can produce more than 10 kW of additional power from light-duty engine waste heat recovery.
- By 2012, enable commercially viable turbocompound units that can produce up to 40 kW of additional power from heavy-duty engine waste heat recovery.

- By 2012, achieve at least 21% efficiency in quantum well thermoelectric devices for waste heat recovery.

This activity also supports the overall engine efficiency goals of the FreedomCAR and Fuel Partnership and 21st CTP.

Programmatic Status

Recovery of energy from the engine exhaust represents a potential for 10% or more improvement in overall engine thermal efficiency. Turbochargers are used to recover part of this energy. Turbochargers currently have efficiencies of around 50 to 58%, which could be increased to 72 to 76% with enhancements such as variable geometry. An electrically driven turbocharger with increased transient response would be another approach. Turbocompounding and direct thermal-to-electric conversion could also improve the overall thermal efficiency. Bulk semiconductor thermoelectric devices are currently 6 to 8% efficient. Recent developments in quantum well thermoelectrics suggest a potential improvement to over 20% is possible.

Targets

The technical targets for Waste Heat Recovery are shown in Table 28.

Table 28. Technical targets: Waste Heat Recovery

Characteristics	Units	Year		
		2003 status	2005	2008
Electrical turbocompound system				
Light-duty vehicles				
Power	kW	<2	>5	>10
Projected component life	hours	<10	>2,000	>5,000
Class 7–8 trucks				
Fuel economy improvement	%	<1	>5	>10
Power	kW	<10	>20	>30
Projected component life	hours	<10	>5,000	>10,000
Thermoelectric devices				
Efficiency				
• bulk semiconductor	%	6–8	--	--
• quantum well			>10	>15
Projected cost/output (250,000 production volume)	$/kW	--	500	180

Barriers

A. **Device/system packaging.** The electro-turbocompound system, including its power electronics and overall system controller, must fit under the vehicle hood with adequate space for cooling. All of the power must be absorbed by the integrated motor/starter/generator or by accessories converted from belt-driven to electric-motor-driven. The turbocharger that has the motor/alternator attached between the turbine and compressor operates at 55,000 rpm for Class 7 and 8 heavy trucks and 120,000 rpm for light trucks. This is pushing the state of the art for the light truck application. This system will increase exhaust gas backpressure, which should be beneficial for NO_x reduction. However, because these systems must not adversely affect emissions, a minimum amount of bearing lube oil can be introduced into the compressor air discharge. The electrocompound system must not cause drivability or NVH problems.

B. **Scale-up to a practical device.** The quantum well thermoelectric concept is a recent technological development. The successful system is essentially a nanostructure consisting of alternate N and P layers about 100 Angstroms thick deposited on an extremely thin silicon substrate. The challenge is to develop coating techniques that can deposit a sufficient number of layers to achieve the efficiency goal. This entails dramatically increasing the size of early devices. Heat transfer in these nanostructure films is exploring new technology. Adequate techniques for measuring key parameters in these nanofilms need to be developed.

C. **Component/system durability.** Specific durability requirements must be met by the waste heat recovery systems. The electric turbocompound system must perform for 250,000 miles and 500,000 miles in light and heavy truck applications, respectively. Quantum well thermoelectric devices will have to survive vibrations encountered in vehicle applications. Although lessons learned with the thermoelectric generator developed with bulk semiconductors will be useful, quantum well thermoelectric devices present a much more difficult challenge because of their more complex fabrication.

D. **Cost.** The electrocompound system capital cost to the owner and operator should be repaid in 24 months or less. This payback period will depend on the cost of the fuel or a tax incentive. For nanothermoelectrics, achieving the large-scale production goal of devices for direct conversion of heat to electricity would require large-scale sputtering equipment that could cost-effectively deposit the layers, possibly in a highly automated manner.

Approach

Iterative test and redesign efforts will be conducted for electric turbocompound systems to validate the electric power produced and the resulting overall engine efficiency gains. In addition, improvements in the low-speed torque will be measured in the context of reducing engine size for the same performance. Validation will be undertaken by motoring the turbocharger during acceleration to reduce turbolag and improve emissions. Testing will also be conducted with EGR-equipped engines to validate NO_x reduction achieved as a result of increased exhaust backpressure.

The technical approach to developing commercially competitive thermoelectric devices[2] for transportation applications is first to validate the bulk semiconductor-based 2-kW thermoelectric generator. The emphasis will be to develop quantum well thermoelectrics (or "nanothermoelectrics") so that they can perform power

[2] A detailed discussion of past efforts in thermoelectrics, the current state of the art for quantum well thermoelectrics, available approaches for improved thermoelectric device performance, present and past R&D tasks by DOE and other entities, as well as detailed steps of the technical approach appear in the document *R&D Approaches to Exploit Recent Major Breakthroughs in Thermoelectrics, for FY 2003–2007*, Office of FreedomCAR and Vehicle Technologies, U.S. Department of Energy, 1000 Independence Avenue, SW, Washington DC 20585, September 2003 draft.

generation (using the Seebeck effect) or heating/cooling (using the Peltier effect) for vehicular applications within the cost criteria for commercial production. A measurement technique for these ultra-thin devices will be developed. Multilayer devices will be made by sputtering with alternate N and P layers (on the order of 1000 layers). Multilayer systems that will initially be investigated include Si/Si0.8Ge0.2 and B4C/B9C deposited on 0.5-mm-thick silicon substrates. Coating parameters will be optimized, and heat transfer issues will be addressed.

Task Descriptions

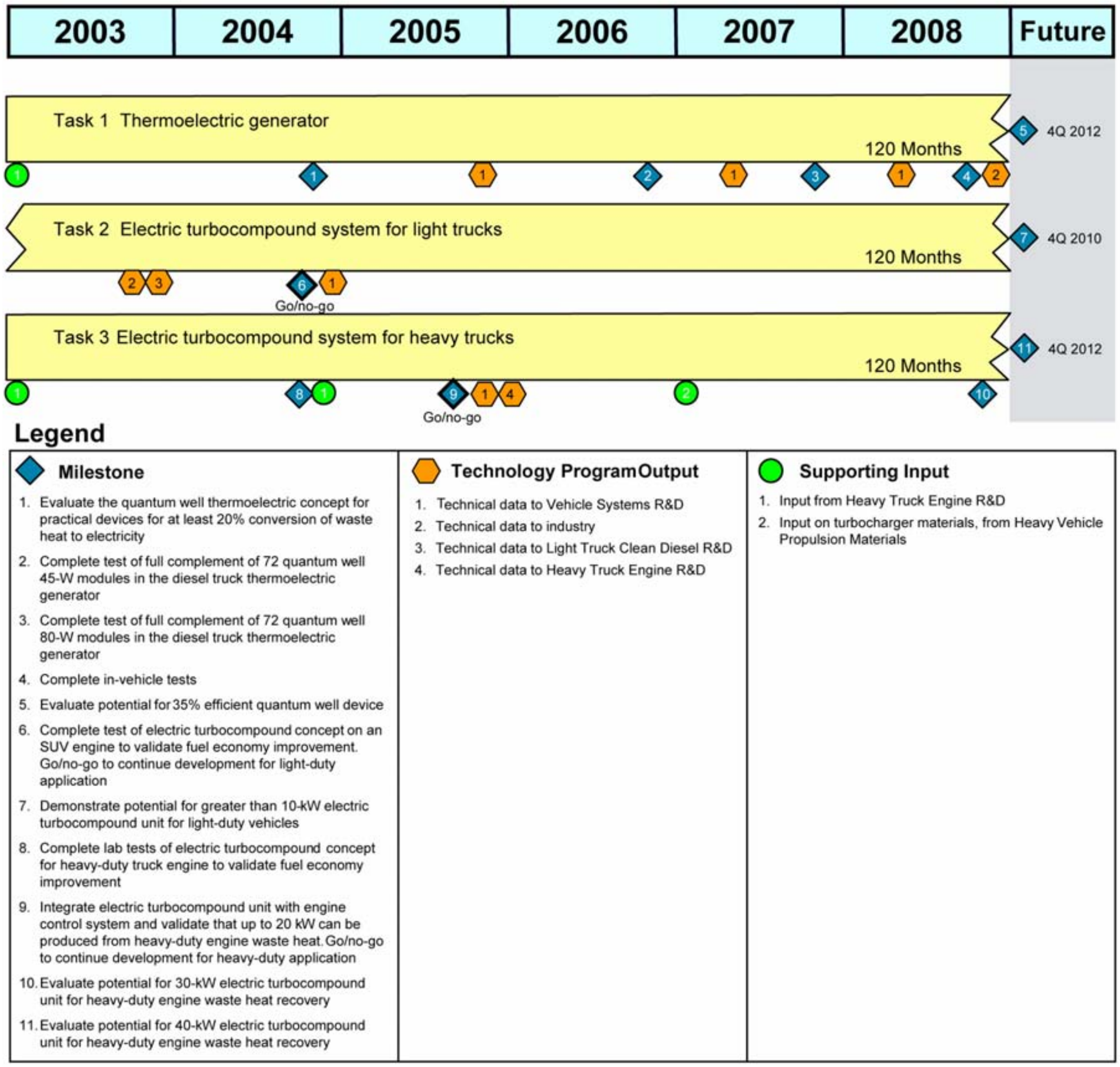
A description of each technical task, along with the estimated duration and technical barriers associated with the task, is provided in Table 29.

Table 29. Tasks for Waste Heat Recovery R&D

Task	Title	Duration/ barriers
1	Thermoelectric generator • Produce 2 kW of electricity from a heavy truck (Class 7 and 8) with a bulk semiconductor thermoelectric generator • Fabricate quantum well device with at least 21% efficiency	120 months Barriers B, C, D
2	Electric turbocompound system for light trucks • Develop electric turbocompound system to deliver 1.8 kW electric power for 2500 h • Test and evaluate a turbocompound system on an SUV engine and validate 10% fuel economy improvement	120 months Barriers A, C, D
3	Electric turbocompound system for heavy trucks • Develop a system to provide an additional 40 kW of electric power • Integrate an electric turbocompound system with heavy truck engine controls and validate through laboratory tests that 40 kW can be produced for over 10,000 h for a 10% fuel economy improvement • Redesign the system using laboratory test results, install the modified electric turbocompound system in a Class 7/8 heavy-duty truck engine, and validate a 10% fuel economy improvement over 10,000 h	120 months Barriers A, C, D

Milestones

The Waste Heat Recovery R&D activity milestones are provided in the following network chart.



4.5.5 Health Impacts

The Health Impacts Research activity supports the FCVT mission to ensure that the more energy-efficient advanced combustion engine technologies are environmentally friendly and do not produce adverse health impacts. This activity seeks to identify, analyze, quantify, and, if possible, avoid potentially deleterious health impacts of new vehicle technologies, specifically of emissions from vehicles using conventional as well as alternative fuels. The emphasis is to place transportation emissions in a proper context, focusing on providing a balance to the portfolio of health research conducted by others.

Goals

The goal of the Health Impacts Research activity is to provide a sound scientific basis for the relationship between mobile-source emissions from new vehicle technologies (engines, fuels, and engine operating conditions or vehicle drive cycles) and their health impacts; more specifically, it is to identify and quantify potential health hazards associated with the use of fuels in transportation vehicle engines.

Programmatic Status

New, "clean" high-efficiency vehicle and fuel technologies may often have unforeseen negative environmental and health impacts. Examples include groundwater contamination by methyl tert-butyl ether (MTBE), an EPA-mandated gasoline additive to reduce carbon monoxide emissions, and findings of carcinogenic compounds (formaldehyde, benzene, 1,3 butadiene) in natural gas vehicle emissions.

To avoid unexpected adverse impacts from the vehicle technologies being developed by FCVT, the Health Impacts Research activity proactively investigates the impacts of changes in fuel, engine, and aftertreatment technologies on the ecosystem and human health. FCVT research on advanced vehicle and fuel technologies is in the exploratory and developmental stages and therefore is not yet sufficiently commercial for EPA regulatory oversight. In addition, this research investigates the health impacts of complex mixtures (e.g., engine exhaust) where toxic synergisms are enhanced and develops information that puts the health impacts of advanced technologies in context with respect to the relative risk from alternative means of providing transportation.

Targets

To determine the impacts of changes in fuels, engines, and aftertreatments on toxics emitted and potential health hazards, accurate measurement methods and tools need to be developed that can be applied to achieve the following:

- Characterize the chemical and physical properties of vehicle emissions and possibly differentiate emissions from various mobile sources (e.g., gasoline- , diesel- , natural gas-fueled vehicles).
- Establish the proper apportionment of emissions among the various mobile sources, e.g., cars vs. heavy trucks.
- Characterize the chemical and physical properties of emissions from farm and construction equipment and locomotives as a function of fuel composition, lubrication technology, and duty cycle.
- Identify potential health impacts from the introduction of new materials, especially composites, into vehicles.
- Establish a scientific basis for determining the impacts of emissions on human health.

Barriers

A. Lack of analytical tools (rapid assay techniques relevant to human toxicity)
B. Lack of credible validated models for mobile source apportionment
C. Lack of validated models for predicting health effects of advanced vehicle technologies

Approach

This work is focused on the development of accurate measurement methods and tools that could be used to place the health hazards from diesel emissions into a proper context relative to emissions from other sources. The contribution of emissions from various mobile sources to the total emissions inventory will be established, as well as the composition of volatile organic compound emissions from petroleum-based diesel, biodiesel, and alternative fuels. Emissions from new and in-use technologies and non-petroleum-based fuels will be evaluated. The atmospheric reactivity of exhaust emissions from alternative-fuel engines will be evaluated to assess the impact on urban air quality relative to conventional fuels. The approach for emissions sampling is as follows:

- Collect samples from in-use vehicles under standardized conditions.
- Measure emission rates.
- Analyze the samples physically and chemically.
- Conduct rapid toxicity tests on samples to determine the potential for cancer and non-cancer effects.
- Compare the types and potencies of toxicity among fuels (e.g., gasoline, diesel, natural gas), engine types, and operating conditions.
- Integrate the analytical and toxicity results into a preliminary understanding of associations between toxicity and physical-chemical classes.

Morphology of the PM emissions will be incorporated into the research task. Impacts of diesel and gasoline PM emissions in atmospheric air will be investigated, compared, and contrasted. Work will also contrast primary and secondary particulates associated with the use of different fuel formulations.

Cooperative research with the Office of Science will be conducted to evaluate the health impacts of particulates from engines combusting alternative fuels and non-petroleum-based fuel blends.

Task Descriptions

A description of each technical task, along with the estimated duration and technical barriers associated with the task, is provided in Table 30.

Table 30. Tasks for Health Impacts Research

Task	Title	Duration/ barriers
1	Evaluation of the relative health hazards of diesel, gasoline, and natural gas engine system(s) emissions	60 months Barriers A,B,C
2	Evaluation of contribution of lubrication oil to the toxicity of engine emissions	24 months Barriers A,B,C
3	Development of new analytical tools required to evaluate health impacts of emerging FCVT technologies	24 months Barriers A,B,C
4	Testing and evaluation of non-petroleum-based fuels for toxic emissions	72 months Barriers A,B,C
5	Evaluation of potential health impacts of new vehicle materials (composites)	24 months Barriers A,B,C

Milestones

Health Impacts Research activity milestones are provided in the following network chart.